# Masked Form Priming as a Function of Letter Position: An Evaluation of Current Orthographic Coding Models

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Running Head: Form Priming/Letter Position

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Abstract

A word's exterior letters, particularly its initial letter, appear to have a special status when reading. Therefore, most orthographic coding models incorporate assumptions giving initial letters and, in some cases, final letters, enhanced importance during the orthographic coding process. In the present paper, three masked priming experiments were carried out, using the conventional lexical decision task, the sandwich priming lexical decision task and the masked priming same-different task, in an attempt to examine a number of those models with a specific focus on the implications of the models' assumptions concerning the different letter positions. The related primes and targets were six-letter strings that differed in two letter positions, initial (e.g., *jnckey*-*HOCKEY*), middle (e.g., *hojney*-*HOCKEY*) or final (*hockjn*-*HOCKEY*), with the middle-letters different primes being the primes that maintained both end letters. To the extent possible, the predictions of the models were derived by using easyNet, the simulation program recently developed by Adelman, Gubian and Davis (in preparation). In all experiments, the final-letters different primes were the most effective primes with there being no clear distinction between the other two prime types, a pattern that none of the models predicted. The lack of an advantage for the middle-letters different primes suggests that the orthographic code driving masked priming is not one that places a special emphasis on the identities of the exterior letters.

Keywords: orthographic coding models, masked priming, letter position

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When attempting to model the process of visual word recognition, one of the key components of that process that must be described is the nature of orthographic coding (Grainger, 2008; 2018). Orthographic coding is the process by which the system determines not only what the letters of the word (that is being read) are but also what the order of those letters is. The question of how a reader accomplishes these goals is one that has attracted considerable attention in recent years, both empirically and theoretically.

Much of the empirical work has involved an evaluation of transposed-letter (TL) effects in lexical decision tasks, effects that cannot be explained by early "slot coding" models (e.g., Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald & Schvaneveldt, 1982; Seidenberg & McClelland, 1989). These effects stem from the fact that when one transposes two letters in a word (e.g., jugde) the resultant letter string is much more perceptually similar to its base word (i.e., JUDGE) than are letter strings in which those same two letters are replaced (e.g., jupte - Guererra & Forster, 2008; Perea & Lupker, 2003a; 2003b; 2004). For example, in an unprimed lexical decision task, *jugde* is harder to reject as a nonword than a two-letter substitution nonword like *jupte* is. A parallel result from the conventional masked priming lexical decision task (a lexical decision task in which target letter strings are preceded by briefly presented primes – Forster & Davis, 1984) is that latencies for the target word *JUDGE* are faster when that word is primed by *jugde* (a transposed-letter nonword) than when it is primed by *jupte* (a substitution-letter nonword). Further, letter strings created by even more extreme transpositions (e.g., *avacitno* which is an anagram of *VACATION* created by transposing successive pairs of letters) can produce masked priming effects regardless of the fact that, at a conscious level, it is quite difficult to determine what word a letter string like *avacitno* is an anagram of (Lupker & Davis, 2009).

At a theoretical level, what has emerged is a number of models that can explain not only TL effects but also a number of other orthographic coding phenomena (e.g., priming effects from primes that mismatch their targets at a single letter position, e.g., *hoise-HOUSE*). The models can generally be divided into two types, what one can call "noisy position" models (Davis, 2010; Gómez, Ratcliff & Perea, 2008; Norris & Kinoshita, 2012; Norris, Kinoshita & van Caasteren, 2010) and what one can call local-context models, specifically, the "open-bigram" models of Grainger, Whitney and colleagues (Grainger & van Heuven, 2003; Grainger, Granier, Farioli, Van Assche & van Heuven, 2006; Schoonbaert & Grainger, 2004; Whitney, 2001; Whitney & Marton, 2013).

The noisy position models are based on the idea that, early in processing, the position of each letter is, to some extent, ambiguous. For example, when reading *jugde*, the system will signal that the most likely position for the *g* is the third position, however, there is some (smaller) probability that it is in either the second or fourth position (and a very small probability that it is in the first or fifth position). Hence, *jugde* is a better prime for *JUDGE* than *jupte* is because the system recognizes that the g and the d in *jugde* are also in *JUDGE* and that there is some probability that they may be in the same positions in the two letter strings.

The local context models are based on the idea that, although the initial, letter-level coding may accurately represent letter positions, the code that actually drives word identification is based on intermediate level representations (between the letter and word levels) involving letter pairs (i.e., bigrams). That is, when reading a word like JUDGE, bigram units representing all (or most) ordered bigrams (i.e., JU, JD, UD, etc.) are activated and it is those units that activate word representations. The reason *jugde* is a better prime than *jupte* for the target *JUDGE* is simply because *jugde* activates more of the bigrams relevant to reading *JUDGE* than *jupte* does.

The general goal of the present research was to continue the evaluation of the various models of orthographic coding. The more specific goal was to examine those models by evaluating their ability to predict masked priming effects as a function of the position(s) at which the primes and targets differ. Following Lupker, Zhang, Perry and Davis's (2015) procedure, three masked priming tasks were used, the conventional masked priming lexical decision task (Forster & Davis, 1984 – Experiment 1), the sandwich priming lexical decision task (Lupker & Davis, 2009 – Experiment 2) and the masked priming same-different task (Norris & Kinoshita, 2008 – Experiment 3).

In a sandwich priming lexical decision task, an additional initial prime is added to the prime-target sequence in the conventional masked priming lexical decision task. Specifically, there is a brief presentation of the target prior to the prime of interest on every trial (the trial sequence would be, for example, *judge-jupte-JUDGE*, where *jupte* is the prime of interest and *judge* is the additional initial prime). One presumed effect of the initial prime is that it heightens the activation of the target representation which will have the effect of making a number of other word representations that would be activated by the prime of interest (or by the target) less effective competitors, essentially allowing a clearer view of the prime of interest's actual impact on the target's processing/representational structures. In line with this idea, the inevitable result of changing from the conventional task to the sandwich priming task is that the sizes of form-level (i.e., orthographic) priming effects typically increase noticeably (Davis & Lupker, 2017; Lupker & Davis, 2009; Lupker et al., 2015).

As Davis (2010) also notes, according to his Spatial-coding model, there is a second reason for the typically observed increase in priming in the sandwich priming task (see also Davis & Lupker, 2017). In fact, in the Spatial-coding model's simulations reported in that paper, this second factor was typically the more important factor at play in simulating the additional priming in sandwich priming tasks. Specifically, when the first prime, which is the target word, is removed, any activated word nodes, most importantly, the target word's node, begin to decay. According to the model, if a second prime is presented immediately, it affects the rate of decay of the target word's node with that rate being a function of the second prime's orthographic similarity to the target. Based on the model's success at simulating sandwich priming effects, what seems most likely is that both factors (reduced lexical competition and a slower decay rate for the target) are responsible for the additional priming in a sandwich priming task.

The masked priming same-different task, first used by Norris and Kinoshita (2008), involves the initial presentation of a visible reference stimulus, followed by a brief masked prime, followed by a target. The task is to decide whether the target and reference stimulus are the same. When they are the same, orthographically similar primes produce significant priming effects, effects that are, like those in the sandwich priming task, inevitably somewhat larger than those in the conventional masked priming lexical decision task. More importantly, unlike what is typically found in masked priming lexical decision tasks, the effects appear to be essentially independent of the frequency or lexical status of the target

(Duñabeitia, Kinoshita, Carreiras & Norris, 2011; Kinoshita & Norris, 2009; Norris & Kinoshita, 2008). The implication of this independence is that the same-different task is most likely mainly reflecting activation at the orthographic level (rather than the lexical level where lexical competition would take place).

The central theoretical issue investigated in the present experiments stems from the long history of the idea that initial letter information is important in reading words (Aschenbrenner, Balota, Weigand, Scaltritti & Besner, 2017; Brühl & Imhoff, 1995; Bruner & O'Dowd, 1958; Guérard, Saint-Aubin, Poirier & Demetriou, 2012; Humphreys, Evett & Quinlan, 1990; Imhoff & Tousman, 1990; Jordan, 1990; Jordan, Thomas, Patching & Scott-Brown, 2003; McCloskey, Fischer-Baum & Schubert, 2013; McKusker, Gough & Bias, 1981; Scaltritti & Balota, 2013; White, Johnson, Liversedge & Rayner, 2008) which is well supported by the available data. What is not obvious from a consideration of that literature, however, is whether the reported effects imply that the initial letter's representation <u>at the orthographic level</u> has a special status that needs to be taken into account by models of the orthographic coding process or whether the effects demonstrating the importance of the initial letter might have been due to some other factor/process, possibly even a more conscious process.

This literature contains, for example, a number of experiments that involve participants reading text presented on a computer screen (Brühl & Imhoff, 1995;

Guérard et al., 2012; White et al., 2008 – Experiment 1), with the typical result being a demonstration that the initial letter position does have some special status. Unfortunately, although these techniques more closely resemble the processes involved in normal reading and, thus, would seemingly have good ecological validity, these types of contrasts are potentially compromised (with respect to the issues being investigated here) by the fact that the initial letter is the most visible letter of the word in the periphery. Hence, due to the obtained peripheral information, the initial letter may be the easiest letter to identify (if the peripheral preview had been correct) or the most difficult to identify (if the peripheral preview had been incorrect) once the word itself is fixated. As such, it's unclear that any observed initial letter effects in these types of experiments would have much to do with the initial letter position having some kind of special status during the orthographic coding process.

A second problem in trying to use the data from a number of the experiments cited above in order to draw conclusions about the nature of orthographic coding, however, is that most of the experimental techniques used lacked control of "lexical constraint" (e.g., Duñabeitia & Carreiras, 2011). Lexical constraint refers to the idea that information about some letters in a word can do a much better job of constraining the set of potential words that might be being read (e.g., New, Araújo & Nazzi, 2008), a factor that can be exploited at a conscious level (e.g., Forster & Shen's, 1996, hypothesis generation process). Importantly, initial letters are typically more constraining than other letters. For example, when a reader is attempting to interpret a letter string in which initial-letter information is disadvantaged/ambiguous (e.g., *udge) versus strings in which other letter information is disadvantaged/ambiguous (e.g., j*dge or ju*ge), it would be much less obvious that the intended word is JUDGE (rather than, for example, FUDGE or BUDGE) in the former situation (i.e., there are no words that can be generated by inserting a different letter into the second or third letter positions in JUDGE).

This issue is relevant because the basic experimental manipulation in many of the experiments showing the importance of the initial letter (e.g., Imhoff & Tousman, 1990; Jorden et al., 2003; McCusker et al., 1981) often involved perceptually disadvantaging one or more letters (with the other letters being presented clearly) and examining the effect on performance. Hence, it's quite possible that findings showing that disadvantaging the initial letter was especially harmful to performance may have been due to factors associated with lexical constraint, rather than differences in the nature of orthographic coding between the initial letter position and the other positions.

There are, of course, a number of experiments in the literature which do not seem to be affected by these two issues, experiments that involve masked priming procedures. Humphreys et al. (1990), for example, used a masked priming, perceptual identification task and, hence, the impact of the primes is unlikely to have had a conscious component and, as well, visibility issues probably did not play a position-differentiating role.[1] Support for the importance of the initial letter in Humphreys et al.'s data, however, is, at best, mixed. In their Experiment 1c, they did report that when their (four-letter) primes and targets shared only a single letter, performance was better when that letter was the initial letter than when it was any of the other letters. Further, in their Experiment 1b, they reported that targets were more readily identified when their (four-letter) primes shared initial and final letters with their targets than when their primes and targets shared any other letter pair. However, also in Experiment 1b, primes sharing the first two letters with their targets were no more effective than primes not sharing first letters (i.e., those sharing the two middle letters or the two final letters). In their Experiment 1a (in which primes shared 3 of 4 letters with their targets), the most effective primes (numerically, although not significantly) were those in which the initial letter was the one letter which was not shared by the prime and target. Hence, based on Humphreys et al.'s data set, it would be hard to make a case for the importance of the initial letter, per se, during the orthographic coding process.

A second data set that allows somewhat of an evaluation of this question comes from Adelman et al.'s (2014) megastudy. Adelman et al. compared priming from primes that mismatched their six-letter targets at either the initial (*fockey-*

*HOCKEY*) or final position (*hockeg-HOCKEY*) with those that mismatched at one of the other four positions. Contrary to what one would expect if the exterior letters were crucial to word identification, the two prime types that did not match their targets in the initial or final positions were actually better primes than the primes mismatching their target at any of the other four letter positions.

Lupker et al. (2015) also provide a general evaluation of this issue. In their experiment, three types of primes were used, initial-letter superset primes (i.e., *zjudge-JUDGE*), middle-letter substitution primes (e.g., *juzge-JUDGE*) and final-letter superset primes (e.g., *judgez-JUDGE*). In their conventional masked priming task, there was no difference between the three prime types. In their sandwich priming and masked priming same-difference tasks, however, the *zjudge* primes were inferior to the other two prime types, a result that would support the importance of the letter in the word's initial position. Everything considered, probably the best summary of the data from these experiments is that support for the idea that the initial letter has a special status in the orthographic code is somewhat mixed.

Interestingly, although it is far from established that the orthographic coding process does give initial (and, possibly, final) letters a special status, many models of this process do assume that such is the case. For example, with respect to the open-bigram models, in Whitney's (2001) SERIOL model, the letter unit for the initial letter has a heightened activation level whereas Whitney and Marton's (2013) model gives the initial and final letters a special status by proposing the existence of edge bigrams (i.e., the bigrams *j and e* are activated when reading JUDGE). In Davis's (2010) Spatial-coding model, letter units representing the exterior letters receive special status by being identified as being exterior letter units ("end-letter marking"). In Gómez et al.'s (2008) Overlap model, the position uncertainty of the initial letter has been assumed to be smaller than that for the other letters. In Adelman's (2011) LTRS model, both of the β parameters relevant to the initial letter position (i.e., the β value for identifying the letter in the initial letter position and the β value for determining that that letter is, indeed, in the initial letter position) are assumed to be greater than those for the letters in the other letter positions. Hence, many of the current models of orthographic coding may be able to provide at least a partial explanation for effects that show a processing advantage for the initial letter.

In an effort to continue our evaluation of the various models of orthographic coding with a focus on the models' assumptions concerning the differential importance of different letter positions, the present research involved three experiments, experiments paralleling those in Lupker et al. (2015). That is, Experiment 1 was a conventional masked priming lexical decision experiment, Experiment 2 was a sandwich priming lexical decision experiment and Experiment

3 was a masked priming same-different experiment. The target stimuli, in all cases, were six-letter words. The position manipulation involved using “related” primes that differed from the target in two letter positions, either the initial positions (i.e., 1 and 2 - referred to as 1/2 primes - the primes that, potentially, may be the least effective because they provide inaccurate information about the target’s initial letter), the middle positions (i.e., 3 and 4 - referred to as 3/4 primes, primes that may be the most effective because they provide accurate information about both of the target’s exterior letters) or the final positions (i.e., 5 and 6 - referred to as 5/6 primes) while matching the target at the other four letter positions.

These types of primes (i.e., two-letter mismatch primes) are not “neighbors” in the Coltheart, Davelaar, Jonasson and Besner (1977) sense. Hence, if the primes were visible, it would often be somewhat difficult to consciously derive an expectation of what the related target word might be in many cases and, to the extent that lexical constraint is potentially an issue in masked priming situations, they would certainly not allow early processing to isolate the target. As a result, they do not tend to produce very large priming effects in the conventional masked priming lexical decision task (Lupker & Davis, 2009; Schoonbaert & Grainger, 2004). Hence, it may be difficult to pick up differences among the prime types, if such differences do exist, in Experiment 1. This problem should be noticeably reduced in Experiments 2 and 3 which employed tasks that have been shown to be much more sensitive to orthographic similarity (e.g., Lupker & Davis, 2009; Lupker et al., 2015; Norris & Kinoshita, 2008).

Models and Model Predictions

The recent development of the easyNet (Adelman, Gubian & Davis, in preparation) software allowed us to derive predictions for performance for a number of implemented models in the conventional (Experiment 1) and sandwich (Experiment 2) priming tasks, specifically, from the most recent version of Davis's (2010) Spatial-coding model, from Adelman's (2011) LTRS model and from a generic open-bigram model (Grainger & van Heuven, 2003) which is the precursor of Schoonbaert and Grainger's (2004) model.[2,3,4] As will be discussed, general predictions in the same-different task (Experiment 3) can be derived directly from similarity scores provided by the relevant models. Hence, we were able to get predictions for a slightly larger set of models for that experiment.

The more central focus will be the Spatial-coding model (Davis, 2010) for the following reasons. First, the model allows for direct predictions of effect sizes in terms of ms, whereas the other two models providing simulations in the two lexical decision experiments (Experiments 1 and 2) only allow predictions of the relative sizes of the priming effects across the various experimental conditions. (A reasonable argument can be made that a transformation of those models' priming effect predictions by multiplying by 10 would provide a good estimate of the models' predicted effect sizes in ms, however, because the simulations do not allow us to specify what the best multiplication factor should be, what will be most relevant to consider is the general pattern of data that those models predict.) Second, in a recent evaluation of a number of models (Davis & Lupker, 2017), the Spatial-coding model provided a better fit to the priming data when using extreme transposition primes (e.g., *cetupmor-COMPUTER*) than all the other models investigated, including some other noisy position models. Finally, Spatial-coding model parameter settings can be altered to allow a contrast between the predictions that the model makes when the end-letter marking assumption (which is what gives exterior letters a special status in the model) is in place with the predictions the model would make if that assumption were dropped. The predictions for the conventional masked priming lexical decision task (Experiment 1) using the stimuli from the present experiments for the three model simulations provided by easyNet are shown in Table 1. Reported there are cycles for the target's lexical unit to reach threshold (which, as just noted, in simulations involving the Spatial-coding model, are scaled to represent effect sizes in ms).

As can be seen, the Spatial-coding model predicts very little priming in the conventional task. Indeed, only the 3/4 primes are predicted to produce any priming at all and only in the situation in which end-letter marking is assumed.

That is, the predicted 8 ms priming effect is essentially a function of the end-letter marking process.

If one assumes that a transformation factor of 10 is legitimate for the LTRS model, that model also predicts very little priming in the conventional task and only a minimal difference between the various prime-type conditions. More relevantly, the pattern the model shows is for less priming from the 1/2 primes, presumably due to the fact that the model gives the initial letter a special status in terms of its assumed β values.

Again assuming a transformation factor of 10, Grainger and van Heuven's (2003) open-bigram model would predict a bit more priming in the conventional task. More importantly, the model suggests a disadvantage for the 3/4 primes (i.e., *hojney-HOCKEY*), those primes that maintain both the initial and final letters in the target. As will be discussed in more detail below, this pattern in which the central letters rather than the exterior letters play a more important role would be expected based on the structure of this model. What is important to note at this point is that this prediction (that the primes that maintain the initial and final letters of the targets should be the weakest primes) is completely the opposite prediction that would be made by a model that gave the initial and final letters special status (e.g., Spatial-coding with the end-letter marking assumption).

The predictions from the three models in the sandwich priming task (Experiment 2) are shown in Table 2. As expected, the Spatial-coding model predicts that the priming effects will be noticeably larger than in the conventional task. If no end-letter marking is assumed, all three prime-type conditions are predicted to produce about 23 ms of priming. If the end-letter marking assumption is made, the same size (i.e., 23 ms) priming effects are predicted for the 1/2 and 5/6 primes (presumably due to the fact that those primes only match their targets in one, but not both, end letter positions). The predicted priming effect, however, is slightly increased for 3/4 primes, those primes that contain the same exterior letters as the target (and, hence, can benefit most from end-letter marking). At a more general level, however, note that what these simulations show is that the impact of end-letter marking is not predicted to be large in the sense that the Spatial-coding model does not predict substantially better priming from the primes that maintain the exterior letters of the target for the stimuli used in the present experiments (i.e., the 3/4 primes). That is, although the model's default assumption is that exterior letters are more important than other letters in the orthographic coding process, the actual impact of making that assumption is somewhat small.

The LTRS model, like the Spatial-coding model, does not predict any large differences between the three prime-type conditions in the sandwich priming task in spite of the fact that the model gives the initial letter a special status in terms of its assumed β values, although as in the conventional task, the 1/2 primes are predicted to produce the smallest priming effect with the 5/6 primes having a small advantage over the 3/4 primes. Note also that, unlike the Spatial-coding model, the LTRS model predicts no increase in priming in the sandwich priming task. Certainly, parameters do exist in the model that could allow that model to predict additional priming in that task, however, at present, the relevant assumptions concerning those parameters have not been implemented.

Grainger and van Heuven's (2003) open-bigram model does predict an increase in priming in the sandwich priming task, however, not for the 3/4 primes. Again, as will be discussed below when deriving model predictions for the same-different task, specifically, predictions from Schoonbaert and Grainger's (2004) open-bigram model which is the essentially direct antecedent of Grainger and van Heuven's model, the nature of the model is such that the 3/4 primes are not considered to be particularly similar to their targets. Hence, a sandwich prime has little ability to inflate what is essentially a minimal priming effect.

No publicly available simulation exists for making predictions for the masked priming same-different task (Experiment 3). However, if that task is, indeed, essentially an orthographically-based task, the orthographic similarity scores obtained from any model that allows calculation of such scores provides a reasonable way of predicting the pattern of effects. (As described by Lupker and

Davis (2009), orthographic similarity scores do not do a good job of predicting priming effects in lexical decision tasks for models that assume lexical competition because they don't take into account the impact of the lexical competition process or of any other lexical process.)  The similarity scores for the three prime types based on the Spatial-coding model are reported in Table 3.  As can be seen there, the Spatial-coding model indicates that primes that mismatch their targets in positions 3 and 4 are more similar to their targets than the other two prime types, again due to the end-letter marking assumption (dropping that assumption would essentially make the difference shown in Table 3 disappear).  However, the difference is, again, not large.  Hence, it's not clear that one would be able to pick up a difference of this magnitude empirically.

In contrast, also included in Table 3 are the similarity scores for three open-bigram models.  The prime type differences for those models are somewhat larger. Specifically, as mentioned above, Schoonbaert and Grainger's (2004) open-bigram model (as well as its antecedent, the Overlap open-bigram model, Grainger et al., 2006) indicate that the 3/4 primes are actually quite dissimilar to their targets and, hence, in contrast to the predictions of the Spatial-coding model, should, presumably, produce substantially smaller priming effects than the other two prime types in Experiment 3.

The reason that these open-bigram models predict small priming effects from 3/4 primes is that they all assume that letters that are too far apart in a word do not activate the relevant open bigram (e.g., when reading HOCKEY, there is no activation of the HY, HE or OY bigrams because the relevant letters are more than 3 letter positions from one another). Essentially, then, most of the bigrams that are activated by the prime involve letters in the middle of the prime. Hence, primes and targets not matching in those middle letter positions (e.g., *hojney-HOCKEY*) will not activate many of the same open bigrams. Therefore, they would not be very similar orthographically and should, as a result, produce only small priming effects in any task. (Note again that, unlike the other models discussed here, these two open-bigram models do not give any special status to the initial or final letters.)

SERIOL (Whitney, 2001) indicates that it is the 1/2 primes that are the least similar to their targets and, hence, presumably, those primes would produce considerably weaker priming than the other two prime types in Experiment 3. The reason is that, in this open-bigram model, the initial letter position is very important and the 1/2 primes do not match their targets at that letter position.

Not included in Table 3 are any predictions for the LTRS model because it does not calculate similarity scores, per se. However, Adelman (personal communications, September 14, 2016; June 2, 2017) indicates that the priming effects in the same-different task should be essentially the same as those observed in the conventional lexical decision task because the priming mechanism is the same in all tasks. That is, one would expect that the 1/2 primes would show the weakest priming.

## Experiments 1, 2 and 3

### *Method*

Participants. The participants were 331 University of Western Ontario undergraduate students who participated for partial course credit, 124 in Experiment 1, 105 in Experiment 2 and 102 in Experiment 3. Participants were removed if they made 25% or more errors on nonword trials or 20% or more errors on word trials. As a result, 10 participants were removed from Experiment 1, leaving 114 participants, and 3 participants were removed from Experiment 2, leaving 102 participants. No participant was removed from Experiment 3 since no participant in that experiment made 20% or more errors on either “same” or “different” trials. No individual participated in more than one experiment. All had normal or corrected-to-normal vision and were native speakers of English.

Materials. In Experiments 1 and 2, the target stimuli consisted of 126 six-letter English words, average CELEX frequency: 22.5 per million, average orthographic neighborhood size (as defined in Coltheart et al., 1977): 0.4 and 126 orthographically legal six-letter nonwords which matched the words in terms of average neighborhood size (0.4 orthographic neighbors). For each word and nonword target, three types of related primes were created, each representing a condition in the experiment: 1) primes created by replacing the first two letters of the target (related 1/2 prime condition; e.g., *jnckey-HOCKEY*), 2) primes created by replacing the middle two letters of the target (related 3/4 prime condition; e.g., *hojney -HOCKEY*), 3) primes created by replacing the final two letters of the target (related 5/6 prime condition; e.g., *hockjn-HOCKEY*). For a given word, the same two substituting letters were used in all conditions. The unrelated conditions were created by re-pairing the primes and targets from the related conditions (e.g., the unrelated primes for *HOCKEY* were the related primes for *DEPART*, *bcpart*, *debcrt* and *depabc* and vice versa). The targets and primes from Experiments 1 and 2 which are also the targets and primes used to create the "same" trials in Experiment 3 are contained in Appendix A.

In order to use all six prime types and allow each target to appear only once to a participant, the 252 targets were divided into six sets of 21 words and 21 nonwords to allow the creation of six stimulus lists across which each target would be primed by each of the six prime types. One-sixth of the participants received each list. Thus, all prime type manipulations were within-subject manipulations.

In Experiment 3, the word targets and their primes from Experiments 1 and 2 were used to create the "same" trials. "Different" trials were created by selecting

252 new six-letter words and using half of them as reference stimuli and the other half as target stimuli (i.e., no nonword targets were used in this experiment). Both the reference stimuli and the targets were matched to the targets on “same” trials in terms of average CELEX frequency (22.8 and 23.2, respectively) and Coltheart et al.’s (1977) N (0.4 in both cases). The reference stimuli and their “different” targets were orthographically dissimilar as they contained no letters in the same letter position. The six types of primes were also used on different trials, however, the relationship that defined the trial was the relationship between the prime and the reference stimulus rather than the prime and the target. (Because the reference stimulus and the target are the identical word on “same” trials, the distinction between the prime-reference relationship and the prime-target relationship is irrelevant on those trials.)

The point of using the prime-reference relationship to define the related “different” trials (a “zero-contingency” manipulation - Perea, Moret-Tatay & Carreiras, 2011), rather than the prime-target relationship, is that in the former case, inhibition effects can emerge when the prime and reference stimulus are orthographically similar (Kinoshita & Norris, 2010; Lupker, Nakayama & Perea, 2015a; Lupker, Perea & Nakayama, 2015b; Perea et al., 2011). Therefore, the results on the “different” trials can potentially provide an additional opportunity to examine the importance of mismatching letters in the various letter positions. The reference stimuli and their associated targets from the “different” trials are listed in Appendix B.

The primes in all the experiments and the reference stimuli in Experiment 3 were displayed in lowercase, whereas all the targets were displayed in uppercase. All stimuli were displayed in size 14 New Courier font. The specific order of presentation of the targets within each list was pseudo-randomized for each participant using Forster and Forster’s (2003) DMDX software.

<u>Procedure.</u> Participants were tested individually. In Experiments 1 and 2, participants were told that their task was to indicate whether the strings of letters presented on the computer screen are English words or not and to press the right shift-key if they think the letter string is a word and the left shift-key if they think it is not. They were also told to do this as quickly and as accurately as possible. No mention was made of the number of stimuli that would be presented on each trial or of the existence of the masked primes. In Experiment 3, participants were told that they would see an initial word in lowercase on the computer screen, followed by a second word in uppercase shortly thereafter. Their task was to indicate whether the two words were the same (except for the difference in case) by pressing the right shift-key if they were the same and the left shift-key if they were different.

In Experiment 1, each trial consisted of the presentation of three stimuli in the same location in the middle of the computer screen. First, a row of six hash marks (######) was presented for 550 ms to serve as a fixation mark, followed immediately by the prime (in lowercase) for 55 ms, followed by the target (in uppercase) for 3 s or until a response was made. In Experiment 2, each trial consisted of the presentation of four stimuli in the same location in the middle of the computer screen. First, the row of six hash marks was presented for 550 ms to serve as a fixation mark, followed immediately by the target word (in lowercase) for 33 ms, followed by the prime of interest (in lowercase) for 55 ms, followed by the target (in uppercase) for 3 s or until a response was made. In Experiment 3, each trial consisted of the presentation of four stimuli. Initially, the reference stimulus (in lowercase) was presented in the upper half of the screen and a row of six hash marks was presented simultaneously in the lower half of the screen for 550 ms. Those stimuli were followed immediately by the prime (in lowercase) for 55 ms, followed by the target (in uppercase) for 3 s or until a response was made, both appearing in the same position on the screen as the row of hash marks. Each stimulus was presented in the vertical center of a 17 inch PC monitor that allowed for an 11 ms refresh rate. Targets (words or nonwords) appeared as black characters on a white background. Reaction times (RTs) were measured from the target's onset until the participant's response.

When the participant responded to a trial, the target disappeared from the screen and the next trial began. All participants in each experiment received 8 practice trials involving a novel set of stimuli prior to the 252 experimental trials. No participants mentioned any awareness of the primes. The entire experiment, in all cases, lasted approximately 15 minutes. This research was approved by the Western University REB (Protocol # 104255).

*Results*

Overall error rates for the 318 participants retained were 4.2% for Experiment 1 (words = 3.1%; nonwords = 5.5%), 4.1% for Experiment 2 (words = 3.3%; nonwords = 5.1%), and 3.6% for Experiment 3 ("same" = 4.8%; "different" = 2.3%). Those trials were removed from the latency analyses. Correct response times faster than 250 ms or slower than 1600 ms were also removed from the latencies analyses (1.6% and 4.6%, of the data for the word and nonword targets, respectively, in Experiment 1, 1.6% and 3.6% for the word and nonword targets, respectively, in Experiment 2, and 0.7% and 1.3%, respectively, for the "same" and "different" trials in Experiment 3). The remainder of the correct responses and the error rates were analyzed using a generalized linear mixed-effects model (GLMM) with a 3 (Prime Position Mismatch: 1/2, 3/4, 5/6) x 2 (Relatedness: Related vs. Unrelated) design separately for the word and nonword targets in Experiments 1 and 2 and for the "same" and "different" trial conditions in

Experiment 3. Prime Position Mismatch and Relatedness (both within-subject and within-item factors) were fixed effects and subjects and items (the target stimuli) were random effects.

In the latencies analyses, a GLMM was used instead of a linear mixed-effects model because generalized linear models, unlike linear models, do not assume a normally distributed dependent variable and can, therefore, better accommodate the typically positively skewed distribution of RT data (Balota, Aschenbrenner, & Yap, 2013; Lo & Andrews, 2015). That is, we decided to use the GLMM and analyze raw RTs rather than following the more common practice of using linear mixed-effects models and normalizing raw RTs with a reciprocal transformation (e.g., invRT = -1000/RT). The reason for this choice is that nonlinear transformations systematically alter the pattern and size of interaction effects, rendering such transformations inappropriate when the research interest lies in interactions, as it does in the present experiments (e.g., Balota et al., 2013; Cohen-Shikora, Suh, & Bugg, in press; Spinelli, Perry, & Lupker, 2019; Yang, Chen, Spinelli, & Lupker, 2019).[5]

A Gamma distribution was used to fit the raw RTs, with an identity link between fixed effects and the dependent variable (Lo & Andrews, 2015). Note that, in the current version of lme4, convergence failures for generalized linear mixed-effects models, especially more complex models run on large data sets, are frequent, although many of those failures reflect false positives (Bolker, 2018). To limit the occurrence of convergence failures, we kept the random structure of the model as simple as possible by using only random intercepts for subjects and items.

Prior to running the model, R-default treatment contrasts were changed to sum-to-zero contrasts (i.e., contr.sum) to help interpret lower-order effects in the presence of higher-order interactions (Singmann & Kellen, 2018). The model was fit by maximum likelihood with the Laplace approximation technique. The lme4 package, version 1.1-18-1 (Bates, Mächler, Bolker, & Walker, 2015) was used to run the generalized linear mixed-effects model. The function Anova in the car package version 2.1-2 (Fox & Weisberg, 2016) was used to obtain estimates and probability values for the fixed effects. Pairwise comparisons for the levels of the Prime Position Mismatch factor, when necessary, were conducted using the emmeans package, version 1.3.1 (Lenth, 2018), with Tukey's HSD adjustment for multiple comparisons. Mean response latencies and error rates for each condition in Experiments 1, 2 and 3 are reported in Table 4.

*Experiment 1, word trials*.

Latencies. The initial model failed to converge. We restarted the initial model from the apparent optimum, as per the recommended troubleshooting procedure (see "convergence" help page in R), and report the results from that model, which did converge. There was an effect of Relatedness, $\chi^2 = 21.32$, $p < .001$, as related primes produced slightly faster latencies than unrelated primes. The Prime Position Mismatch factor was also significant, $\chi^2 = 14.83$, $p < .001$. This effect reflected overall faster latencies for 5/6 primes compared to 1/2 primes, ß = 9.17, *SE* = 2.56, *z* = 3.59, *p* = .001, and 3/4 primes, ß = 7.98, *SE* = 2.55, *z* = 3.13, *p* = .005 (1/2 primes and 3/4 primes did not differ from each other, ß = 1.19, *SE* = 2.35, *z* = .51, *p* = .87). Most importantly, there was a marginal interaction between Prime Position Mismatch and Relatedness, $\chi^2 = 5.36$, $p = .069$, reflecting the fact 5/6 primes produced a larger priming effect (17 ms) than 1/2 primes (7 ms) and 3/4 primes (9 ms).[6]

Error Rates. There were no main effects and no interactions in the error analyses (all *p*s > .20).

*Experiment 1, nonword trials*.

Latencies. There was an effect of Relatedness, $\chi^2 = 4.31$, $p = .038$, reflecting slightly faster latencies following related than unrelated primes. No other effect was significant (all *p*s > .35).

Error Rates. There were no main effects and no interactions in the error analyses (all *p*s > .15).

*Experiment 2, word trials*.

Latencies. There was an effect of Relatedness, $\chi^2 = 152.44$, $p < .001$, as related primes produced faster latencies than unrelated primes. The Prime Position Mismatch factor was not significant, $\chi^2 = 2.91$, $p = .23$. Most importantly, the interaction was significant, $\chi^2 = 9.54$, $p = .008$. Post-hoc analyses revealed that this interaction reflected the fact that the 40-ms priming effect for 5/6 primes was larger than the 21-ms priming effect for 3/4 primes, $\chi^2 = 7.98$, $p = .005$, and the 27-ms priming effect for 1/2 primes, $\chi^2 = 5.11$, $p = .024$. The priming effects for 1/2 and 3/4 primes also did not differ, $\chi^2 = .65$, $p = .42$.

Error Rates. There was a main effect of Relatedness, $\chi^2 = 5.45$, $p = .020$, as error rates were lower following related primes. Prime Position Mismatch was not significant, $\chi^2 = 4.27$, $p = .12$. The interaction was marginal, $\chi^2 = 4.77$, $p = .092$, because of a tendency for a larger priming effect for 3/4 primes than for 1/2 primes.

*Experiment 2, nonword trials*.

Latencies. In the model restarted from the apparent optimum (the initial model failed to converge), there were no main effects and no interactions (all *p*s > .10).

Error Rates. The only effect that approached significance was a marginal interaction between Prime Position Mismatch and Relatedness, $\chi^2 = 5.61$, $p = .061$, reflecting a tendency for a larger priming effect following 5/6 primes than following 1/2 and 3/4 primes.

*Experiment 3, "same" trials*.

Latencies. The initial model failed to converge, as did the model restarted from the apparent optimum. As per the recommended troubleshooting procedure (see "convergence" help page in R), model evaluation was performed using all available optimizers. Except for the default optimizer and the nloptwrap optimizer, the optimizers produced similar results, suggesting that the convergence warning was a false positive. We report the results from the BOBYQA optimizer.

There was a main effect of Relatedness, $\chi^2 = 433.92$, $p < .001$, as related primes produced faster latencies than unrelated primes. The main effect of Prime Position Mismatch was also significant, $\chi^2 = 30.31$, $p < .001$. Responses to 1/2 primes were slower than responses to 3/4 primes, *ß* = 12.62, *SE* = 2.53, $z = 4.98$, $p < .001$, and responses to 5/6 primes, *ß* = 9.98, *SE* = 2.56, $z = 3.90$, $p < .001$ (responses to 3/4 primes and 5/6 primes did not differ from each other, *ß* = -2.64, *SE* = 2.44, $z = -1.08$, $p = .53$). More importantly, the interaction was also significant, $\chi^2 = 16.94$, $p < .001$. Post-hoc analyses revealed that this interaction reflected different size priming effects for 1/2, 3/4, and 5/6 primes: The 49-ms priming effect for 5/6 primes was larger than both the 32-ms priming effect for 1/2 primes, $\chi^2 = 16.58$, $p < .001$, and the 40-ms priming effect for 3/4 primes, $\chi^2$ =

4.90, $p = .027$; the 40-ms priming effect for 3/4 primes was also larger than the 32-ms priming effect for 1/2 primes, $\chi^2 = 4.32$, $p = .038$.[7]

Errors. There was a main effect of Relatedness, $\chi^2 = 63.73$, $p < .001$, reflecting more accurate responses to related than unrelated primes. Prime Position Mismatch was not significant, $\chi^2 = 3.92$, $p = .14$. However, there was a significant interaction, $\chi^2 = 7.79$, $p = .020$. Post hoc analyses revealed that this interaction arose because priming effects were larger for 5/6 primes (.040) than for 1/2 primes (.021), $\chi^2 = 7.71$, $p = .005$. The priming effect for 3/4 primes (.032) did not significantly differ from that for either the 1/2 primes or the 5/6 primes (both *p*s > .10).

*Experiment 3, "different" trials.*

Latencies. The initial model failed to converge, as did the model restarted from the apparent optimum. As per the recommended troubleshooting procedure (see "convergence" help page in R), model evaluation was performed using all available optimizers. The optimizers produced similar results, suggesting that the convergence warning was a false positive. We report the results from the BOBYQA optimizer, which did converge.

There was a main effect of Relatedness, $\chi^2 = 18.57$, $p < .001$, as related primes produced slower latencies than unrelated primes. There was no effect of Prime Position Mismatch, $\chi^2 = .29$, $p = .86$, however, there was a marginal interaction between Prime Position Mismatch and Relatedness, $\chi^2 = 5.76$, $p = .056$. This marginal interaction reflects a larger inhibition effect for the 3/4 primes (19 ms) than for the 1/2 primes (2 ms), $\chi^2 = 4.54$, $p = .033$. The inhibition effect for 5/6 primes (5 ms) did not significantly differ from that for either the 1/2 primes or the 3/4 primes (both *p*s > .15).

Errors. In the model restarted from the apparent optimum (the initial model failed to converge), there were no main effects and no interactions (all *p*s > .10).

*Discussion*

Although the details varied a bit from experiment to experiment, the data did follow a couple of general patterns. The first is that, as is typical, the priming effects were larger in Experiments 2 and 3 than in Experiment 1. The findings that are more central to the present discussion, however, are that: a) the best primes seemed to be the 5/6 primes, those that maintained the initial four letters in the target and b) there was little, if any, evidence that the 3/4 primes, those primes maintaining the exterior letters in the target, were better than even the 1/2 primes. With the possible exception of the LTRS model, this pattern of results is not particularly consistent with any of the models under consideration.

More specifically, in the conventional task of Experiment 1, there was a small but significant overall priming effect and there was numerical evidence for a larger priming effect (17 ms) in the 5/6 condition with the 9 ms priming effect in the 3/4 condition being indistinguishable from the 7 ms effect in the 1/2 condition. In Experiment 2, there was a significant interaction between Prime Position Mismatch and Relatedness due to the fact that the 5/6 primes showed a significantly larger priming effect (40 ms) than the 1/2 primes (27 ms) and a significantly larger priming effect than the 3/4 primes (21 ms). That is, in Experiment 2, it was the 3/4 primes that produced the weakest priming. In the "same" trials in Experiment 3, a similar type of pattern emerged. There was a significant interaction with the 5/6 primes producing a significantly larger priming effect (49 ms) than both the 1/2 primes (32 ms) and the 3/4 primes (40 ms). The only seeming break from this pattern was the analysis of the "different" trials in Experiment 3. Here, even though the interaction was not significant in any of the analyses, the 3/4 primes produced a 19 ms (inhibitory) priming effect which was significantly larger than that for the 1/2 primes (2 ms) but not that for the 5/6 primes (5 ms) in the post-hoc analyses.

At the most general level, what these results show is that model assumptions concerning there being a differential importance for exterior letters during the orthographic coding process (e.g., the Spatial-coding model's end-letter marking assumption, the LTRS model with higher β values for the initial letter, SERIOL's added weight on the initial letter) are, at best, unnecessary for explaining the priming data or, at worst, contraindicated by the present priming data. A more detailed discussion of the various models follows in the General Discussion.

## General Discussion

The present set of experiments was an examination of a number of models of orthographic coding with a specific focus on the potential impact of letter position on the orthographic coding process. As noted, many current models of orthographic coding assume that the initial (and, sometimes, final) letter in a word gains a special status due to the nature of that process. The literature is clear in showing that initial letters do have some sort of special status in reading. Our basic question was whether the models are correct in assuming that at least part of that status derives from the process of orthographic coding.

The data from Experiments 1, 2 and 3 suggest that a shared final letter between the prime and the target is, if anything, less important than shared letters in other positions. The present experiments also provide little evidence that the initial letter is more important than the letters in other positions. Thus, these experiments provide essentially no support for the assumptions of a number of models of orthographic coding that give initial (or final) letters some sort of special status during that process (e.g., SERIOL, Spatial-coding if the end-letter marking assumption is made).

*Open-bigram Models*

The only open-bigram model that has been computationally implemented and, therefore, can be simulated using easyNet software is Grainger and van Heuven's (2003) model. That model is, however, the basis of Schoonbaert and Grainger's (2004) model and shares much of its structure not only with that model but also with Grainger et al.'s (2006) model. That structure is such that, according to all of these models, our 3/4 primes are predicted to provide less priming than our 1/2 and 5/6 primes due to the fact that our 3/4 primes share fewer open bigrams with their targets than the other two prime types do. The easyNet simulations indicate that this predicted difference (according to Grainger and van Heuven's model) is not large in the conventional task where all three prime conditions are predicted to produce relatively small amounts of priming. However, the predicted difference grows substantially when overall priming effects are larger, as in the sandwich priming task (Experiment 2) and the same-different task (Experiment 3), as can be seen in Tables 2 (the sandwich priming simulation) and 3 (the similarity scores for the 2004 and 2006 models). The results in these experiments (i.e., that, the 3/4 primes are essentially as effective as the 1/2 primes) are, as noted, quite inconsistent with these predictions.

The reason these models make these predictions is, as mentioned, not because of the way the models treat initial letters but rather because of the assumptions they make about which open bigrams are activated during reading (i.e., if two letters are too far apart, for example, the H and Y in HOCKEY, the HY open bigram is not activated). Note that, in Grainger and van Heuven's (2003) paper, there was also the proposal of an "unconstrained" open-bigram model, that is, a model based on the assumption that all the possible open bigrams are activated when processing a letter string. A model making that assumption would not predict a 3/4 prime disadvantage, however, it would not predict our 5/6 prime advantage either. In any case, the viability of an "unconstrained" open-bigram model was strongly challenged by Grainger et al.'s (2006) results, causing those authors to reject that model.

Whitney's (2001) SERIOL model is also an open-bigram model. That model, however, has a slightly different structure, one that does not predict a 3/4 prime disadvantage. Rather, it predicts that the 1/2 primes are the related primes that are most dissimilar to their targets (see Table 3). The result should be a large 1/2 prime disadvantage. Although there was some evidence that 1/2 primes were the worst primes in Experiment 3, such was not the case in either Experiment 1 or Experiment 2.

*Adelman's (2011) LTRS Model*

In Experiment 1, the predictions of the LTRS model were the closest to the obtained data. That is, the model predictions of priming effects of 7, 10 and 11 ms (which would be obtained by multiplying the differences reported in Table 1 by 10) were very similar to the obtained effect sizes of 7, 9 and 17 ms. Further, the model does predict that the 5/6 primes should be the best primes in both Experiments 1 and 2. Thus, in general, it would seem to have done the best job of accounting for the present data among the models being considered here in spite of the fact that it does give special status to the initial letter, both in terms of identifying it and locating it more rapidly than the other letters. Where the model falters, however, is that: a) it fails to make much of a distinction between the 3/4 and 5/6 primes while seeming to make more of a distinction between 3/4 and 1/2 primes and b) the current parameter settings of the LTRS model do not allow that model to predict the overall larger priming effects that emerge in the sandwich priming task or in the same-different task. While it's certainly possible that new parameter settings could be selected for that model that would allow it to deal with those issues, it's unclear whether doing so would then affect the model's ability to predict other data patterns.

*Davis's (2010) Spatial-coding model*

The model examined most closely in the present research was Davis's (2010) Spatial-coding model. This model did not have great amount of success dealing with the data either. That is, when the end-letter marking assumption was maintained, the model predicted a 3/4 priming advantage, albeit only a small one, a result that did not arise. When that assumption was dropped, the model predicted no differences among the various conditions, rather than the 5/6 priming advantage that was observed. A further difficulty this model had in these experiments was that it essentially failed to predict any priming effects in Experiment 1.

In considering what changes might be useful to make to the model, perhaps the first question would be, "Would it be better to drop the end-letter marking assumption?" In terms of having it or not, as Davis (2010) notes after comparing predicted priming effects across 61 different experiments (pp. 748-749), the correlation between predictions with and without the assumption is .92 (i.e., there is little difference between the model's predictions with versus without the assumption). Why, therefore, was the assumption included in the ultimate version of model?

The first reason is that the model did tend to do a slightly better job of predicting the 61 priming effects examined by Davis (2010) when the assumption was included. Of these 61 effects, the predictions with and without the assumption are within 3 ms of one another (i.e., virtually identical) in 23 cases. In the other 38 cases, the model with the assumption provided a better prediction than the model without the assumption in 28 of them. Focussing specifically on the experimental conditions when the priming manipulation involved exterior letters (p. 750), there are 21 such effects. For 9 of those, the predictions are within 3 ms of one another.

Of the remaining 12, the model with the assumption provided a better prediction than the model without the assumption in 8 cases. Therefore, based on this analysis of the experimental literature prior to the publication of the Spatial-coding model in 2010, it is the case that maintaining the end-letter marking assumption does provide at least a small advantage.

The second reason Davis (2010) included the end-letter marking assumption in the ultimate version of the Spatial-coding model derives from the general literature. He noted that, as discussed above, there are a large number of demonstrations in that literature (e.g., Bruner & O'Dowd, 1958; Chambers, 1979; Holmes & Ng, 1993; Perea & Lupker, 2003a; Schoonbaert & Grainger, 2004; Rayner, White, Johnson & Liversedge, 2006; White et al., 2008) showing an initial-letter advantage on various tasks. The end-letter marking assumption could provide a means for explaining those types of results. As noted earlier, however, many of those results are potentially explainable in ways that do not implicate the orthographic coding process. Therefore, it would appear that those data patterns do not provide a strong argument for maintaining the assumption.

With respect to explaining the present data, however, the challenge would be substantial, explaining the fact that the 3/4 primes (which contained both the marked letters in the target) were not better than the 1/2 primes (which did not contain the initial letter) as well as explaining the superiority of the 5/6 primes (in spite of the fact that the final letter in the target was missing from the prime). Dropping the end-letter marking assumption for the final letter would cause the model to no longer predict that 3/4 primes would be better than 5/6 primes but the model would still predict that they would be inferior to 1/2 primes. Dropping the assumption for the initial letter would allow the model to predict similar performance for the 3/4 and 1/2 primes, however, there would not appear to be a way to change this assumption to allow the model to explain the 5/6 priming advantage in the present experiments.

*Two final questions*

The first question is, given the failure of the models examined to explain the 5/6 priming advantage, what type of model/assumptions would be needed in order to explain such a pattern? At a general level, what would be needed would be an assumption (or a set of assumptions) that gives less weight to the letters in final part of a word. One type of assumption that could be adopted would be one which involves some sort of serial left-to-right scan of the orthographic code or that the code involved a diminishing left-to-right activation pattern across the letters. In fact, ideas of this sort are contained in Whitney's (2001) SERIOL model. As noted, however, the SERIOL model itself, places considerable importance on the initial letter causing the model to predict that 1/2 primes should be ineffective primes. Hence, the parameters of a successful model would need to be selected in a somewhat different fashion, one which, rather than reflecting a strong impact of the initial letter, instead reflected a fairly weak impact of the final letters.

An alternative way to explain the 5/6 priming advantage would be to suggest that it was due to the impact of subword codes. This type of idea could follow from Taft's (1979; 1987) Basic Orthographic Syllable Structure (BOSS) model. According to this model, one role of orthographic processing is to isolate a unit referred to as the BOSS which is defined as "the first part of the stem morpheme of a word, up to and including all consonants following the first vowel, but without creating an illegal consonant cluster in its final position" (Taft, 1987, p. 265). The BOSS of many six-letter words in English is four letters long as were the informative parts of the related 5/6 primes. Therefore, if the BOSS of both our primes and targets were four letters in length, that fact could potentially explain why the 5/6 primes were the best primes.

It seems unlikely, however, that the BOSS idea, per se, would be able to explain the present data. Of the 126 targets, only 44 of them had four-letter BOSSes. (Further, of those 44, only 39 had primes in which the prime's BOSS matched the BOSS of the target.) Of the remaining 82 targets, 46 of them had three-letter BOSSes with the remaining 36 having two-, five- or six-letter BOSSes. For these 82 targets, their BOSS would not have been well represented in the 5/6 primes. That is not to say, of course, that the 5/6 priming advantage was not due to the impact of other types of word initial subword units (e.g., Rumelhart & Siple; 1974; Spoehr & Smith, 1973), units that overlapped in the 5/6 primes and targets. Additional research would be needed in order to shed some light on this possibility.

The second question is, if the initial letter in a word does not have a special status in the orthographic code, what is the source of the initial letter effects in the literature? Given the extent of that literature, it would be impossible to have a complete discussion of this issue here, however, a couple of potentially important (nonorthographic) factors can be noted which may have been responsible for producing the various first letter effects.

An obvious factor is legibility. That is, the first letter in a word presented to the right is closer to fixation than other letters and, in central presentations, the first letter suffers less from lateral masking than the rest of the letters, with the exception of the final letter. A second factor is lexical constraint which likely affects performance in experiments in which some letters are presented earlier than others. As first letters likely benefit less from the lexical constraint created by the other letters in the word, when their presentation is disadvantaged (or rendered ambiguous), it is not surprising that word identification is more hampered than when other letters are disadvantaged (or rendered ambiguous).

Both of these factors were noted in the Introduction and they were not meant to be an exhaustive list. An additional factor, that was not mentioned previously, is the impact of phonological processing. When trying to identify a briefly presented word, the reading process will likely try to create a phonological code based on the perceived letters. Construction of that code will usually be done in a left-to-right fashion meaning that the phonological code for the initial letter will be derived first and, indeed, may be the only phonological code that can be derived from a brief exposure duration. As a result, if the phonological code can provide any aid in terms of report, the first letter would be advantaged.

One can find support for this type of idea in the masked onset priming literature. The relevant paradigm in this literature is the masked priming naming task. When the prime and target share an onset phoneme (in alphabetic languages), a priming effect is observed (e.g., Forster & Davis, 1991; Kinoshita, 2000; Malouf & Kinoshita, 2007; Schiller, 2004). Such is not the case when the prime and target start with the same letter but not the same phoneme (e.g., *cement-CONGRESS*) (Schiller, 2007; Timmer & Schiller, 2012), indicating that the effect is clearly a phonological effect based on some memory representation created by the initial letter of the masked prime. If the first letter in a briefly presented word does, indeed, allow activation of its phonological code (but the phonological codes of other letters are not generally activated due to limited processing time), it would not be surprising to find that memory for that letter would be better than memory for other letters in a variety of experimental paradigms.

*Conclusions*

The goal of the present research was to examine a number of models of orthographic coding with a special emphasis on the assumptions those models make about the coding of the exterior letters in the word being read. The general pattern observed was that manipulations involving six-letter primes and targets that mismatched at various letter positions produced larger priming effects when the mismatch occurred at positions 5 and 6. This pattern of results was quite problematic for the open-bigram models considered here, even though many of those models were not models that make special assumptions regarding the initial (or final) letter position. Most versions of those models predict that the worst primes should be those mismatching at positions 3 and 4. It was also problematic for the Spatial-coding model which, at least when making the end-letter marking assumption, predicts that the primes mismatching at positions 3 and 4 would be the best primes.

The results were, potentially, least problematic for the LTRS model which, to some degree, can predict the 5/6 prime advantage even though it also seems to predict a 1/2 prime disadvantage in comparison to 3/4 primes. A model that can predict the entire pattern would seem to be one in which the identities of letters in the later positions are regarded as less diagnostic than those in the earlier positions with no special emphasis being placed on the initial letter.

## Footnotes

[1] Lexical constraint created by the nature of a prime is not an irrelevant factor in experiments in which the prime is masked and unavailable for use in a conscious fashion (Duñabeitia & Carreiras, 2011; Perry, Lupker & Davis, 2008). However, Humphreys et al.'s (1990) four-letter word stimuli were somewhat less likely to create a situation in which the different prime types created different levels of lexical constraint due to the fact that there are so many four-letter words in English. When longer stimuli are used, the lexical constraint issue becomes a bit more important and needs to be monitored. For example, in Lupker et al. (2015), in which the prime and target stimuli were all five or more letters long, an attempt was made to avoid problems of this sort by selecting stimuli that, according to Davis's (2010) Spatial-coding model, which is sensitive to lexical constraint, would not lead to differential priming effects for Lupker et al.'s three prime types. What needs to be kept in mind, however, is that even when an effort is made to equate the prime type conditions in terms of lexical constraint, the means of doing so must be based on whatever assumptions are being made about the structure of the lexicon (e.g., what are a word's "orthographic neighbors"?). Successfully equating prime types, therefore, depends on those assumptions being at least approximately correct.

[2] Although easyNet attempts to use simulations that match the proposed models as closely as possible, except for the Spatial-coding and LTRS models, the easyNet simulations were not designed by the original creators of the models. Therefore, it is possible that these predictions are slightly, although not significantly, different than what would be predicted by the models' creators. Such is most likely to be true in the case of sandwich priming which, prior to easyNet, had not been conceptualized within any of the models other than the Spatial-coding model.

[3] Note two additional issues with respect to the LTRS model. First, as the model is a stochastic model, its predictions were determined by running the model 25 times and taking the average results as the model's predictions. Second, the creator of the LTRS model has indicated that the simulation is still slightly off in terms of its predictions (Adelman, personal communication). This problem is minimized, however, because the present discussions of that model focus on the pattern of its predictions rather than the details of those predictions.

[4] Grainger and van Heuven's (2003) open-bigram model is the only computational implementation of an open-bigram model currently available and the version we examined does an excellent job of capturing predictions in a number of form priming experiments. For example, its predictions correlate .90 with the mean

priming effects obtained in the various conditions investigated in the form priming megaproject (Adelman et al., 2014).

[5] The data were also analyzed using the more conventional $F_1/F_2$ procedure. The only difference between the results of those analyses and those from the GLMM analyses was that some of the marginal effects in the conventional analyses were significant using the GLMM procedure.

[6] Although the interaction was not significant, at the request of one of the reviewers, we also analyzed the priming effects in each condition separately. The effects in the 1/2 and 3/4 conditions were marginal at best (for the 1/2 condition, *ß* = -6.50, *SE* = 3.46, $z = -1.88$, $p = .061$; for the 3/4 condition, *ß* = -6.28, *SE* = 3.73, $z = -1.68$, $p = .093$) whereas the effect in the 5/6 condition was significant (*ß* = -16.86, *SE* = 3.68, $z = -4.58$, $p < .001$).

[7] At the request of one of the reviewers, we also carried out an analysis comparing the size of the priming effect in Experiment 1 with that in Experiment 2 and with that in Experiment 3 (for the "same" trials). As noted in the Introduction, the expectation was that the priming effects should be larger in the latter two experiments. The Experiment by Relatedness interaction was significant in both analyses (Experiment 1 vs Experiment 2 - $\chi^2 = 34.41$, $p < .001$; Experiment 1 vs Experiment 3 - $\chi^2 = 103.31$, $p < .001$) indicating that the priming effects were significantly larger in Experiment 2 and Experiment 3 than in Experiment 1.

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Table 1 – Predicted priming effects (in cycles) in Experiment 1 (conventional masked priming lexical decision task) for Davis's (2010) Spatial-coding model (with and without the end letter marking assumption), for Adelman's (2011) LTRS model and Grainger and van Heuven's (2003) open-bigram model.

Davis's (2010) Spatial-coding model

| | With end-letter marking | | | Without end-letter marking | | |
|---|---|---|---|---|---|---|
| Prime type | Rel | Unrel | Effect | Rel | Unrel | Effect |
| 1-2 mismatch | 105 | 106 | 1 | 108 | 108 | 0 |
| 3-4 mismatch | 98 | 106 | 8 | 104 | 107 | 3 |
| 5-6 mismatch | 104 | 105 | 1 | 107 | 108 | 1 |

Adelman's (2011) LTRS model

| Prime type | Rel | Unrel | Effect |
|---|---|---|---|
| 1-2 mismatch | 109.63 | 110.29 | .66 |
| 3-4 mismatch | 109.31 | 110.36 | 1.05 |
| 5-6 mismatch | 109.13 | 110.26 | 1.13 |

Grainger & van Heuven's (2003) open-bigram model

| Prime type | Rel | Unrel | Effect |
|---|---|---|---|
| 1-2 mismatch | 21.99 | 24.63 | 2.64 |
| 3-4 mismatch | 22.98 | 24.69 | 1.71 |
| 5-6 mismatch | 21.99 | 24.57 | 2.58 |

Table 2 – Predicted priming effects (in cycles) in Experiment 2 (sandwich priming lexical decision task) for Davis's (2010) Spatial-coding model (with and without the end letter marking assumption), for Adelman's (2011) LTRS model and Grainger and van Heuven's (2003) open-bigram model.

Davis's (2010) Spatial-coding model

| | With end-letter marking | | | Without end-letter marking | | |
|---|---|---|---|---|---|---|
| Prime type | Rel | Unrel | Effect | Rel | Unrel | Effect |
| 1-2 mismatch | 81 | 104 | 23 | 84 | 106 | 22 |
| 3-4 mismatch | 70 | 103 | 33 | 80 | 105 | 25 |
| 5-6 mismatch | 80 | 103 | 23 | 82 | 105 | 23 |

Adelman's (2011) LTRS model

| Prime type | Rel | Unrel | Effect |
|---|---|---|---|
| 1-2 mismatch | 111.84 | 112.34 | .50 |
| 3-4 mismatch | 111.63 | 112.32 | .69 |
| 5-6 mismatch | 111.61 | 112.42 | .81 |

Grainger & van Heuven's (2003) open-bigram model

| Prime type | Rel | Unrel | Effect |
|---|---|---|---|
| 1-2 mismatch | 22.27 | 26.83 | 4.56 |
| 3-4 mismatch | 24.98 | 26.81 | 1.83 |
| 5-6 mismatch | 22.21 | 26.71 | 4.50 |

Table 3 – Similarity scores between the targets and both related and unrelated primes of each type from Experiments 1, 2 and 3 according to the Spatial-coding model and three open-bigram models. (The column labeled "Diff" reflects the relative size of the predicted priming effect.)

| | Prime Type | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1/2 mismatch | | | 3/4 mismatch | | | 5/6 mismatch | | |
| | Rel | Unrel | Diff | Rel | Unrel | Diff | Rel | Unrel | Diff |
| Spatial-Coding | .62 | .18 | .44 | .75 | .19 | .56 | .62 | .17 | .45 |
| Schoonbaert/Grainger (2004) open-bigram | .50 | .03 | .47 | .25 | .03 | .22 | .50 | .03 | .47 |
| Overlap open-bigram Grainger et al. (2006) | .58 | .03 | .55 | .31 | .03 | .28 | .58 | .04 | .54 |
| SERIOL open-bigram Whitney (2001) | .13 | .03 | .10 | .62 | .05 | .57 | .55 | .03 | .52 |

Table 4 – Mean latencies (in ms) and error rates (in parentheses) in Experiments 1 (conventional masked priming), 2 (sandwich priming) and 3 (masked priming same-different task)

Experiment 1 (conventional masked priming lexical decision task)

| Prime type | Rel | Unrel | Priming Effect |
|---|---|---|---|
| 1-2 mismatch | 669 (.025) | 676 (.034) | 7 (.009) |
| 3-4 mismatch | 667 (.033) | 676 (.030) | 9 (-.003) |
| 5-6 mismatch | 655 (.030) | 672 (.031) | 17 (.001) |

Experiment 2 (sandwich priming lexical decision task)

| Prime type | Rel | Unrel | Priming Effect |
|---|---|---|---|
| 1-2 mismatch | 638 (.033) | 665 (.032) | 27 (-.001) |
| 3-4 mismatch | 643 (.028) | 664 (.045) | 21 (.017) |
| 5-6 mismatch | 630 (.024) | 670 (.034) | 40 (.010) |

Experiment 3 (masked priming same-different task)

| | | Same trials | |
|---|---|---|---|
| Prime type | Rel | Unrel | Priming Effect |
| 1-2 mismatch | 529 (.043) | 561 (.064) | 32 (.021) |
| 3-4 mismatch | 512 (.031) | 552 (.063) | 40 (.032) |
| 5-6 mismatch | 511 (.024) | 560 (.064) | 49 (.040) |

| | | Different trials | |
|---|---|---|---|
| Prime type | Rel | Unrel | Inhibition Effect |
| 1-2 mismatch | 583 (.021) | 581 (.021) | -2 (.000) |
| 3-4 mismatch | 592 (.022) | 573 (.020) | -19 (-.002) |
| 5-6 mismatch | 586 (.032) | 581 (.021) | -5 (-.011) |

# Appendix A

Word targets and primes in Experiments 1 and 2 and for the "same" trials in Experiment 3.

| | Related | | | Unrelated | | |
|---|---|---|---|---|---|---|
| Targets | 1/2 primes | 3/4 primes | 5/6 primes | 1/2 primes | 3/4 primes | 5/6 primes |
| CRADLE | nzadle | crnzle | cradnz | dmatch | sndmch | snatdm |
| HOCKEY | jnckey | hojney | hockjn | bcpart | debcrt | depabc |
| TRANCE | yzance | trytce | tranyt | smchor | ansmor | anchsm |
| TRENCH | mzench | trmzch | trenmz | psenzy | frpszy | frenps |
| INDUCE | lmduce | inlmce | indulm | hvrlic | gahvic | garlhv |
| GUITAR | hcitar | guhcar | guithc | cdrupt | abcdpt | abrucd |
| THRIVE | ygrive | thygve | thriyg | knspel | goknel | gospkn |
| STREAK | dpreak | stdpak | stredp | ymvern | goymrn | goveym |
| VANISH | mxnish | vamxsh | vanimx | cfarve | stcfve | starcf |
| FLUENT | hyuent | flhynt | fluehy | ghurdy | stghdy | sturgh |
| SNATCH | dmatch | sndmch | snatdm | ghmine | faghne | famigh |
| DEPART | bcpart | debcrt | depabc | nzadle | crnzle | cradnz |
| ANCHOR | smchor | ansmor | anchsm | jnckey | hojney | hockjn |
| FRENZY | psenzy | frpszy | frenps | ytance | trytce | tranyt |
| GARLIC | hvrlic | gahvic | garlhv | mzench | trmzch | trenmz |
| ABRUPT | cdrupt | abcdpt | abrucd | lmduce | inlmce | indulm |
| GOSPEL | knspel | goknel | gospkn | hcitar | guhcar | guithc |
| GOVERN | ymvern | goymrn | goveym | ygrive | thygve | thriyg |
| STARVE | cfarve | stcfve | starcf | dpreak | stdpak | stredp |
| STURDY | ghurdy | stghdy | sturgh | mxnish | vamxsh | vanimx |
| FAMINE | ghmine | faghne | famigh | hyuent | flhynt | fluehy |
| CLAUSE | dcause | cldcse | claudc | djuity | eqdjty | equidj |
| DISMAY | blsmay | diblay | dismbl | tcbris | detcis | debrtc |
| LIQUOR | yzquor | liyzor | liquyz | ypetch | skypch | sketyp |
| PLUNGE | kiunge | plkige | plunki | cprand | stcpnd | stracp |
| BUNKER | tznker | butzer | bunktz | dmouse | bldmse | bloudm |
| LOCATE | imcate | loimte | locaim | rcield | shrcld | shierc |
| CANDLE | tkndle | catkle | candtk | mtyage | vomtge | voyamt |
| PLAGUE | diague | pldiue | plagdi | ndnkey | mondey | monknd |
| RADIUS | tcdius | ratcus | raditc | wlctor | viwlor | victwl |
| SPONGE | tconge | sptcge | spontc | mclgar | vumcar | vulgmc |
| EQUITY | djuity | eqdjty | equidj | lcform | inlcrm | infolc |
| DEBRIS | tcbris | detcis | debrtc | dcause | cldcse | claudc |
| SKETCH | ypetch | skypch | sketyp | blsmay | diblay | dismbl |
| STRAND | cprand | stcpnd | stracp | yzquor | liyzor | liquyz |
| BLOUSE | dmouse | bldmse | bloudm | kiunge | plkige | plunki |
| SHIELD | rcield | shrcld | shierc | tznker | butzer | bunktz |
| VOYAGE | mtyage | vomtge | voyamt | imcate | loimte | locaim |
| MONKEY | ndnkey | mondey | monknd | tkndle | catkle | candtk |

| | | | | | | |
|---|---|---|---|---|---|---|
| VICTOR | wlctor | viwlor | victwl | diague | pldiue | plagdi |
| VULGAR | mclgar | vumcar | vulgmc | tcdius | ratcus | raditc |
| INFORM | lcform | inlcrm | infolc | tconge | sptcge | spontc |
| RESIGN | ycsign | reycgn | resiyc | ipunge | loipge | lounip |
| THRONE | yjrone | thyjne | throyj | jiumsy | cljisy | clumji |
| RECKON | pgckon | repgon | reckpg | jmsult | injmlt | insujm |
| DOMAIN | ylmain | doylin | domayl | muvolt | remult | revomu |
| ETHNIC | klhnic | etlkic | ethnkl | lnport | imlnrt | impoln |
| THREAD | jgread | thjgad | threjg | hybric | fahyic | fabrhy |
| CLIENT | hdient | clhdnt | cliehd | qdcket | buqdet | buckqd |
| KNIGHT | pmight | knpmht | knigpm | ycrkey | tuycey | turkyc |
| SOLEMN | dglemn | sodgmn | soledg | lnpose | imlnse | impoln |
| ADJUST | pljust | adplst | adjupl | dkream | scdkam | scredk |
| LOUNGE | ipunge | loipge | lounip | ctndle | buctle | bundct |
| CLUMSY | jiumsy | cljisy | clumji | ycsign | reycgn | resiyc |
| INSULT | jmsult | injmlt | insujm | yjrone | thyjne | throyj |
| REVOLT | muvolt | remult | revomu | pgckon | repgon | reckpg |
| IMPORT | lnport | imlnrt | impoln | ylmain | doylin | domayl |
| FABRIC | hybric | fahyic | fabrhy | klhnic | etlkic | ethnkl |
| BUCKET | qdcket | buqdet | buckqd | jgread | thjgad | threjg |
| TURKEY | ycrkey | tuycey | turkyc | hdient | clhdnt | cliehd |
| IMPOSE | lnpose | imlnse | impoln | pmight | knpmht | knigpm |
| SCREAM | dkream | scdkam | scredk | dglemn | sodgmn | soledg |
| BUNDLE | ctndle | buctle | bundct | pljust | adplst | adjupl |
| ABSENT | dcsent | abdcnt | absedc | dlnema | cidlma | cinedl |
| COMEDY | btmedy | cobtdy | comebt | gtndom | ragtom | randgt |
| PISTOL | ygstol | piygol | pistyg | cnploy | emcnoy | emplcn |
| CARBON | dgrbon | cadgon | carbdg | tguise | crtgse | cruitg |
| EXPAND | vmpand | exvmnd | expavm | klaise | prklse | praikl |
| BRONZE | tconze | brtcze | brontc | lknior | julkor | junilk |
| CUSTOM | dgstom | cudgom | custdg | gtapel | chgtel | chapgt |
| PENCIL | bfncil | pebfil | pencbf | drbtle | sudrle | subtdr |
| ADMIRE | gnmire | adgnre | admign | gyudio | stgyio | studgy |
| PERMIT | ghrmit | peghit | permgh | mlwder | pomler | powdml |
| CINEMA | dlnema | cidlma | cinedl | ghlumn | coghmn | colugh |
| RANDOM | gtndom | ragtom | randgt | dcsent | abdcnt | absedc |
| EMPLOY | cnploy | emcnoy | emplcn | btmedy | cobtdy | comebt |
| CRUISE | tguise | crtgse | cruitg | ygstol | piygol | pistyg |
| PRAISE | klaise | prklse | praikl | dgrbon | cadgon | carbdg |
| JUNIOR | lknior | julkor | junilk | vmpand | exvmnd | expavm |
| CHAPEL | gtapel | chgtel | chapgt | tconze | brtcze | brontc |
| SUBTLE | drbtle | sudrle | subtdr | dgstom | cudgom | custdg |
| STUDIO | gyudio | stgyio | studgy | bfncil | pebfil | pencbf |
| POWDER | mlwder | pomler | powdml | gnmire | adgnre | admign |
| COLUMN | ghlumn | coghmn | colugh | ghrmit | peghit | permgh |
| SYMBOL | kjmbol | sykjol | symbkj | jtance | gljtce | glanjt |

| | | | | | | |
|---|---|---|---|---|---|---|
| WEAPON | ylapon | weylon | weapyl | gctain | obgcin | obtagc |
| GENIUS | ytnius | geytus | geniyt | gkther | bogker | bothgk |
| IGNORE | jdnore | igjdre | ignojd | tpldom | setpom | seldtp |
| BISHOP | glshop | biglop | bishgl | ksince | prksce | prinks |
| BURDEN | gcrden | bugcen | burdgc | mlngue | tomlue | tongml |
| AUTHOR | gcthor | augcor | authgc | pcngry | hupcry | hungpc |
| ORANGE | tyange | ortyge | oranty | gtrase | phgtse | phragt |
| VOLUME | gnlume | vognme | volugn | nkrvey | sunkey | survnk |
| BELONG | tqlong | betqng | belotq | btgion | rebton | regibt |
| GLANCE | jtance | gljtce | glanjt | dnpect | asdnct | aspedn |
| OBTAIN | gctain | obgcin | obtagc | kjmbol | sykjol | symbkj |
| BOTHER | gkther | bogker | bothgk | ylapon | weylon | weapyl |
| SELDOM | tpldom | setpom | seldtp | ytnius | geytus | geniyt |
| PRINCE | ksince | prksce | prinks | jdnore | igjdre | ignojd |
| TONGUE | mlngue | tomlue | tongml | glshop | biglop | bishgl |
| HUNGRY | pcngry | hupcry | hungpc | gcrden | bugcen | burdgc |
| PHRASE | gtrase | phgtse | phragt | gcthor | augcor | authgc |
| SURVEY | nkrvey | sunkey | survnk | tyange | ortyge | oranty |
| REGION | btgion | rebton | regibt | gnlume | vognme | volugn |
| ASPECT | dnpect | asdnct | aspedn | tqlong | betqng | belotq |
| CREDIT | lnedit | crlnit | credln | zhavel | trzhel | travzh |
| FACTOR | gkctor | fagkor | factgk | gjland | isgjnd | islagj |
| SENIOR | hynior | sehyor | senihy | gzrest | fogzst | foregz |
| SILVER | mylver | simyer | silvmy | hnject | obhnct | objehn |
| BRANCH | ytanch | brytch | branyt | jnarge | chjnge | charjn |
| PLENTY | mdenty | plmdty | plenmd | pkable | stpkle | stabpk |
| SEARCH | dtarch | sedtch | seardt | mfance | stmfce | stanmf |
| WEALTH | nzalth | wenzth | wealnz | hzurce | sohzce | sourhz |
| CASTLE | dkstle | cadkle | castdk | hysign | dehygn | desihy |
| SILENT | mjlent | simjnt | silemj | ktuare | sqktre | squakt |
| TRAVEL | zhavel | trzhel | travzh | gzrect | digzct | diregz |
| ISLAND | gjland | isgjnd | islagj | lnedit | crlnit | credln |
| FOREST | gzrest | fogzst | foregz | gkctor | fagkor | factgk |
| OBJECT | hnject | obhnct | objehn | hynior | sehyor | senihy |
| CHARGE | jnarge | chjnge | charjn | mylver | simyer | silvmy |
| STABLE | pkable | stpkle | stabpk | ytanch | brytch | branyt |
| STANCE | mfance | stmfce | stanmf | mdenty | plmdty | plenmd |
| SOURCE | hzurce | sohzce | sourhz | dtarch | sedtch | seardt |
| DESIGN | hysign | dehygn | desihy | nzalth | wenzth | wealnz |
| SQUARE | ktuare | sqktre | squakt | dkstle | cadkle | castdk |
| DIRECT | gzrect | digzct | diregz | mjlent | simjnt | silemj |

Appendix B

Reference stimuli and targets for the “different” trials in Experiment 3.

| Reference stimuli | Targets |
|---|---|
| FUTILE | STARCH |
| SPLASH | COWARD |
| POLLEN | THIRST |
| SANITY | POETIC |
| GLADLY | SAILOR |
| BETRAY | TACTIC |
| GREASY | RUNWAY |
| CLUTCH | LEGION |
| ORDEAL | PLEDGE |
| POTENT | REFLEX |
| SLOGAN | ASHORE |
| UNJUST | ARCTIC |
| JARGON | ENTITY |
| SPIRAL | NEPHEW |
| SLEEPY | ACCORD |
| INWARD | DERIVE |
| COFFIN | ATTACH |
| PARCEL | REMEDY |
| IRONIC | FEEBLE |
| SHREWD | AGENDA |
| COLONY | RECIPE |
| OUTFIT | SAMPLE |
| CELLAR | ENDURE |
| TRIBAL | SUBMIT |
| MIGHTY | EXOTIC |
| POTATO | ADVISE |
| CEREAL | RHYTHM |
| OCCUPY | PURSUE |
| STATIC | DIVIDE |
| ABSORB | DEPUTY |
| INVITE | COMBAT |
| WORTHY | RESCUE |
| PARDON | REGIME |
| POISON | REGRET |
| HAMMER | REJECT |

| | |
|---|---|
| GOTHIC | ARREST |
| BRUTAL | CAMPUS |
| PARADE | COUSIN |
| SPHERE | INSIST |
| SOLELY | INFANT |
| CIRCUS | INJURY |
| INSANE | POETRY |
| SENATE | FORGOT |
| INTEND | SALARY |
| CLINIC | BEHAVE |
| STATUE | TENNIS |
| GOSSIP | FREELY |
| SAVAGE | PROFIT |
| TREATY | MARBLE |
| OPENLY | SELECT |
| GLOBAL | TENURE |
| PETROL | AVENUE |
| MARINE | TOILET |
| LIABLE | ARTIST |
| OPTION | ENABLE |
| BUREAU | LAWYER |
| WISDOM | NEARBY |
| SOFTLY | GARAGE |
| ABSURD | DEVICE |
| LIQUID | MUSCLE |
| SCREEN | REMOTE |
| OUTPUT | CLEVER |
| POLISH | LEAGUE |
| MODEST | DEPEND |
| SOONER | PRIEST |
| UNIQUE | CASUAL |
| PALACE | STRESS |
| UNLIKE | DESERT |
| GOLDEN | STEADY |
| CIRCLE | ANNUAL |
| GUILTY | MIRROR |
| BEAUTY | ACCESS |
| CHOSEN | BOTTLE |
| MEMORY | FOURTH |
| CHOOSE | FIRMLY |

| | |
|---|---|
| SCHEME | VISION |
| LISTEN | SAFETY |
| NOTICE | PARENT |
| SPREAD | FALLEN |
| BROKEN | ADVICE |
| DEMAND | SUPPLY |
| ACCEPT | MINUTE |
| INCOME | APPEAR |
| ABROAD | RESUME |
| BREAST | DISMAL |
| CAMERA | SERMON |
| CANVAS | LEGACY |
| CHEESE | RIBBON |
| COFFEE | VERSUS |
| CONVOY | ETHICS |
| CORPSE | FISCAL |
| DEFEAT | EDIBLE |
| DEFEND | VIABLE |
| DEVOTE | TARGET |
| FUSION | WEAKEN |
| GREEDY | BALLOT |
| HOLLOW | PUNISH |
| HUMANE | LESSON |
| INTACT | HEROIC |
| LETHAL | UNFAIR |
| MENACE | STOLEN |
| MORALE | LUXURY |
| OFFSET | KINDLY |
| OUTSET | REVEAL |
| PEPPER | ASSESS |
| PICNIC | AFFECT |
| SALUTE | RECALL |
| SEWAGE | ATTEND |
| TOMATO | MEADOW |
| TUNNEL | MANAGE |
| UNSEEN | REMOVE |
| VANITY | ASLEEP |
| CANCEL | MUSEUM |
| GALAXY | ARISEN |
| UNREAL | COSMIC |

| | |
|---|---|
| VELVET | PURPLE |
| SCRIPT | BEATEN |
| LOWEST | ENGINE |
| TRAGIC | PREFER |
| VACUUM | RESIST |
| ABOARD | MOTIVE |
| MOBILE | UNREST |
| DEEPLY | STRICT |
| SUDDEN | RELISH |
| HORROR | SACRED |
| SEASON | HATRED |